The MINHA Project

Model of an **I**ntense **N**onscaling **H**adron **A**ccelerator

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Project Overview

- Nonscaling FFAG for protons have several possible advantages, but some issues to address
- Electron model of **proton driver** proposed to study issues, develop technology -- **MINHA**
- Other work ongoing to improve simulations
- Our scope: **hardware** development

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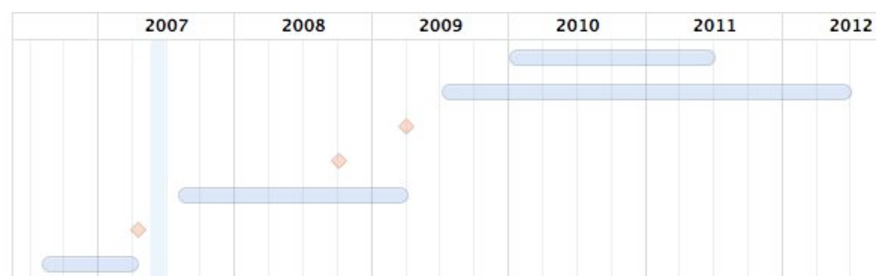
Project Overview

- Recently finished conceptual design
- Next step is to build and test **prototype** components (octant beamline)
- End goal is a full electron model

Task
- 1) Sales of Electron Model Components
- 2) Full Electron Model Project: MINHA
- 3) Prototype Tests Complete
- 4) Prototype Octant/Cavity Fabricated
- 5) Phase II SBIR
- 6) Conceptual Design Complete
- 7) Phase I SBIR



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FFAG Accelerators

- Fixed-Field = magnets aren't pulsed
  - Like cyclotrons; not synchrotrons
- Alternating-Gradient = strong focusing
  - Focusing comes from both AG and edges
- FFAG is a hybrid
  - Not isochronous like the cyclotron, but can be **zero chromaticity**
  - Smaller magnet radial apertures + not pulsed = cheap
  - Not CW like cyclotron, but much higher rep rate compared to synchrotron

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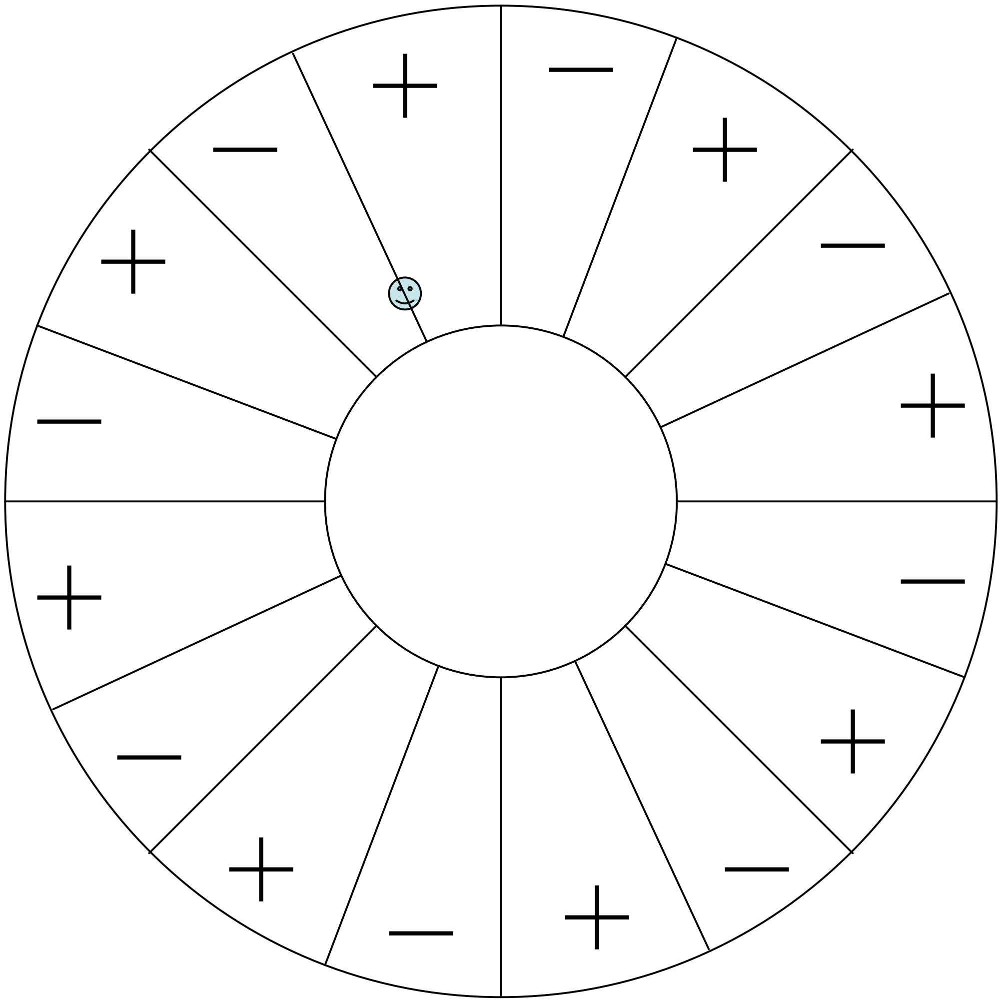
FFAG Movie



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FFAG Applications

- Applied to electrons:
  - Increases current capability of the betatron
  - Less expensive injector for storage rings (e.g. eRHIC)
- Applied to muons
  - Ideal for muon acceleration due to large acceptance and fixed fields
- Applied to **protons**
  - Improvement over the rapid-cycling synchrotron -- rep rate can be kHz not Hz
  - CW acceleration? (harmonic number jump)

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Scaling FFAGs

- Scaling FFAGs have fields designed to keep tunes constant:

$$B = B_0 \left(r / r_0 \right)^k f(\theta)$$

- To achieve this field, must use pole-face windings
- Can approximate with pole-shaping
  - but introduces large fringe field, some tune change, reduces acceptance

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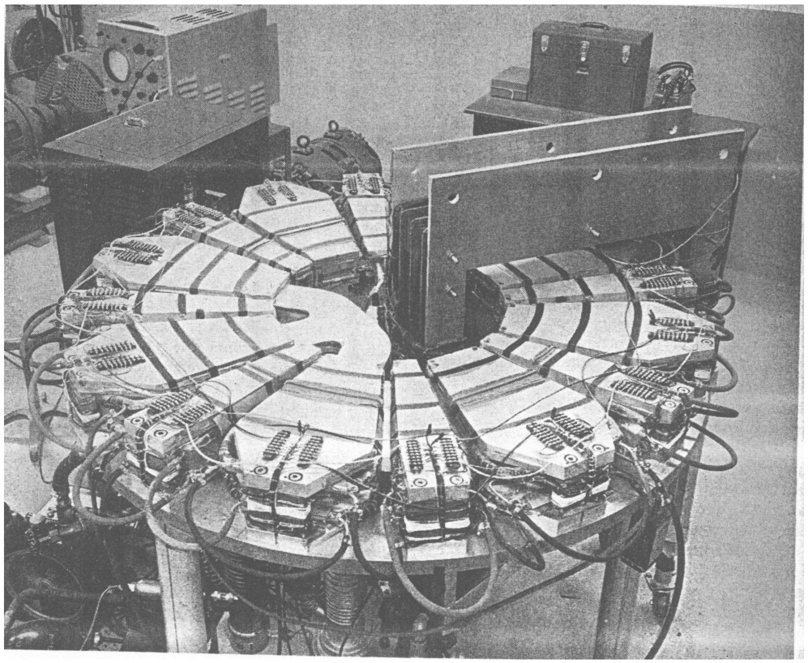
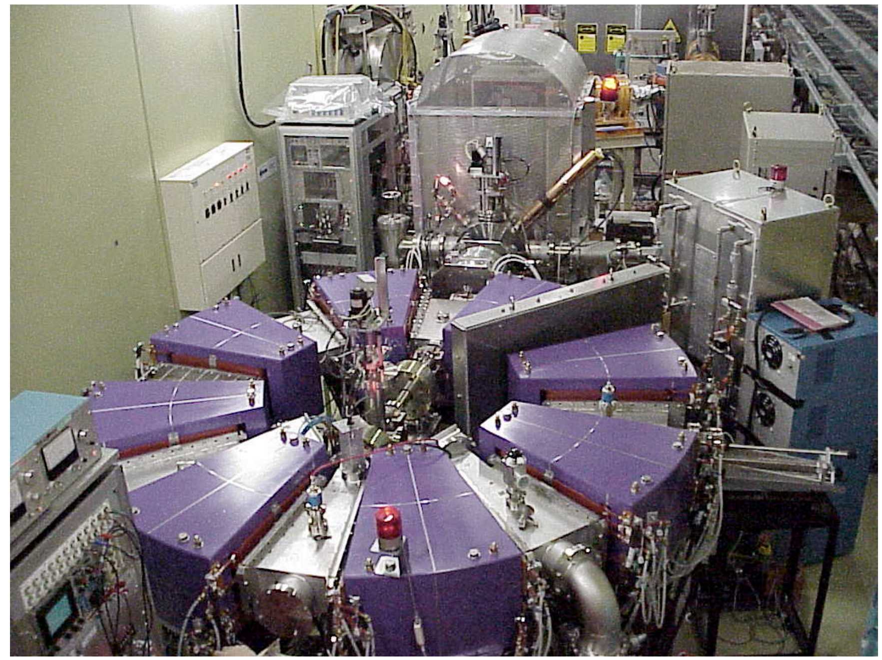
Scaling FFAG Pictures



MURA 8 sector Radial FFAG (1956)



KEK 8 sector Proton FFAG synchrotron (2000)

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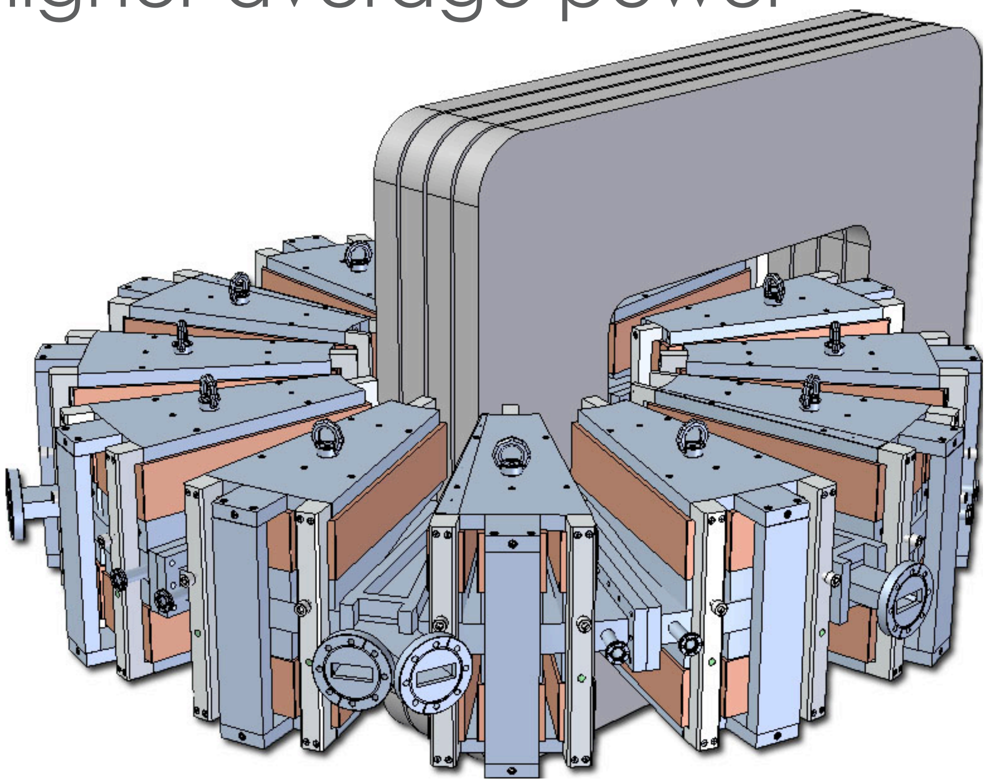
The Radiatron

- FFAG focusing applied to betatron allows much higher average power



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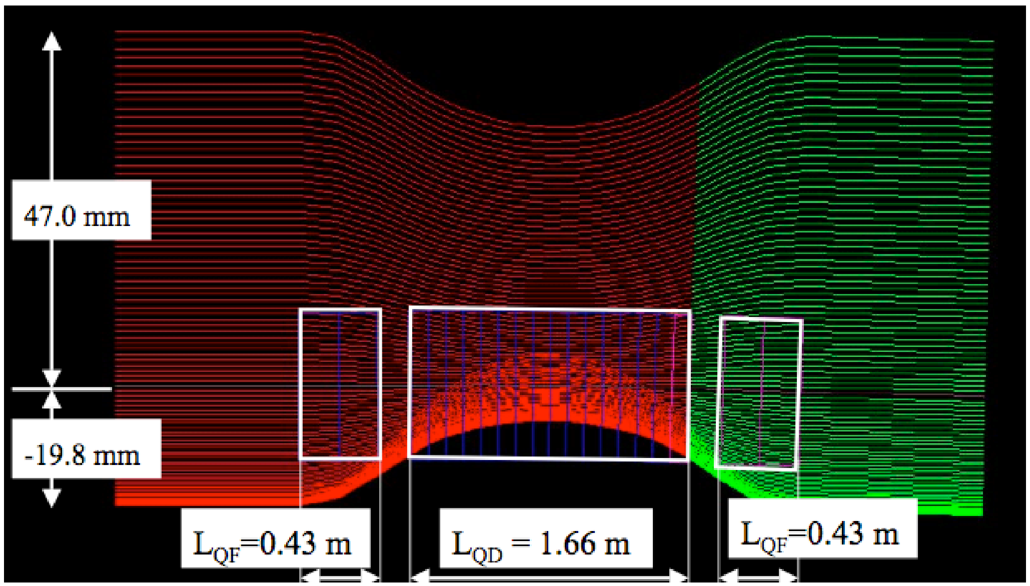
Nonscaling FFAGs

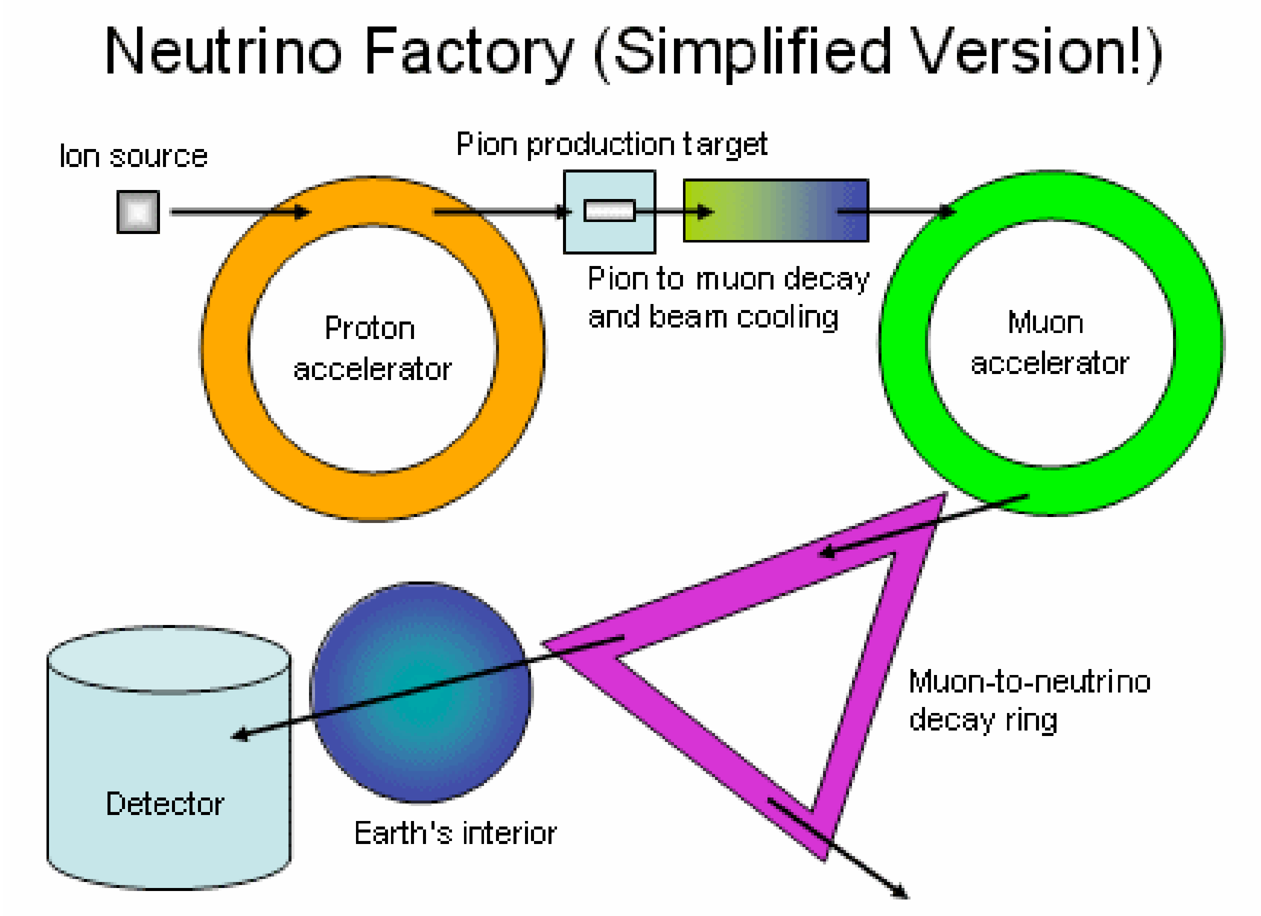
- FFAG with non-zero chromaticity
- Can be used to optimize for dispersion
- Can simplify magnets with linear fields



Nonscaling FFAG for Protons

- Applications:
  - Secondary particle production (muons, neutrinos, neutrons, etc)
  - Waste transmutation/subcritical reactor
  - Proton (or anti-proton) therapy
- Issues:
  - Fast sweeping RF cavity
  - Resonance crossing
  - Space charge etc.

Neutrino Factory



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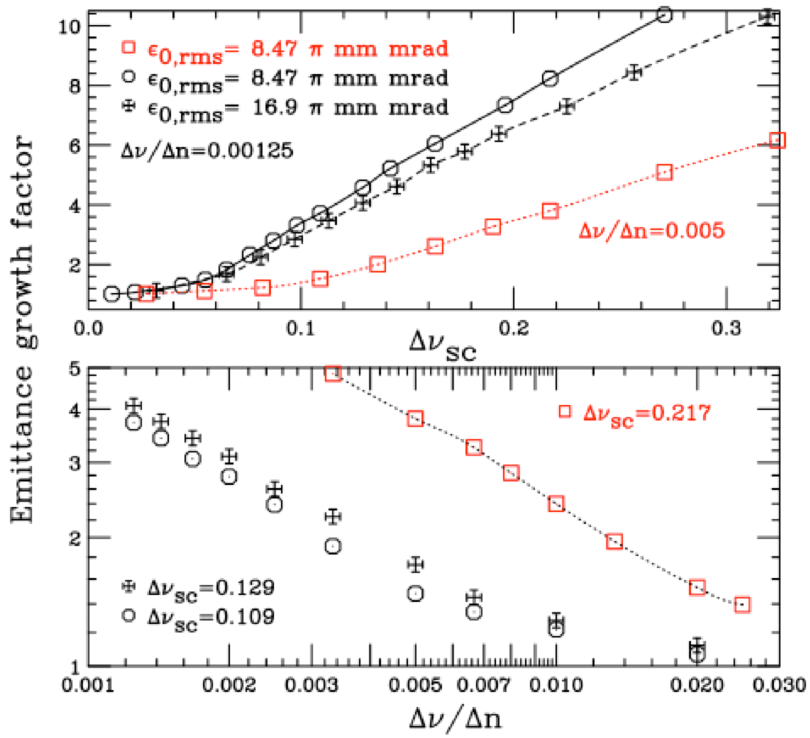
High Current Issues

- Multiple Resonance Crossing
  - SY Lee, Phys. Rev. Letters 97, 104801 (2006)

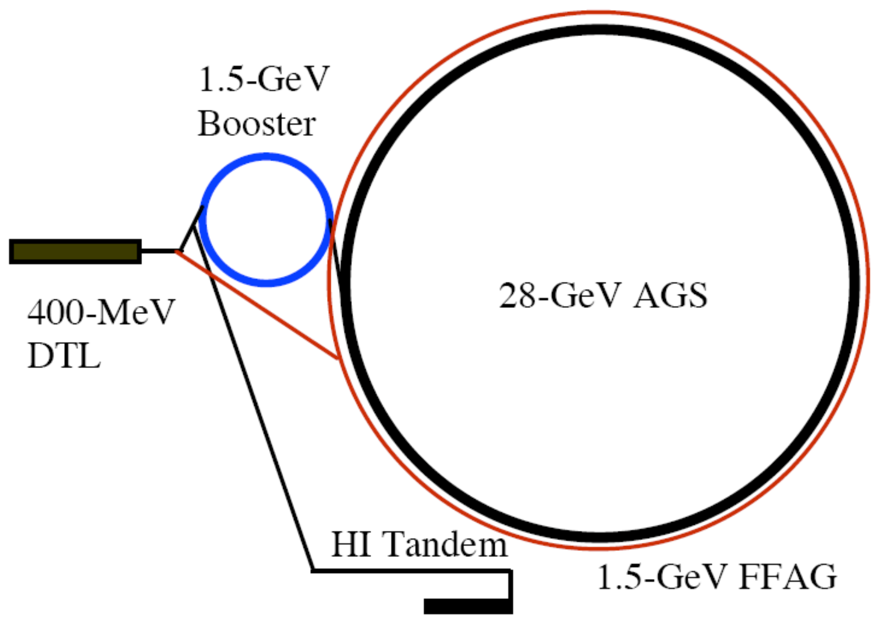


Electron Model

- Phase I: Conceptual design
- Phase II: Engineering, prototype testing
- Phase III: The full model built and tested
- Starting point: AGS booster upgrade

The AGS FFAG Booster

- 400 MeV - 1.5 GeV
- 10^{14} ppp, 5 Hz
- 2 MW



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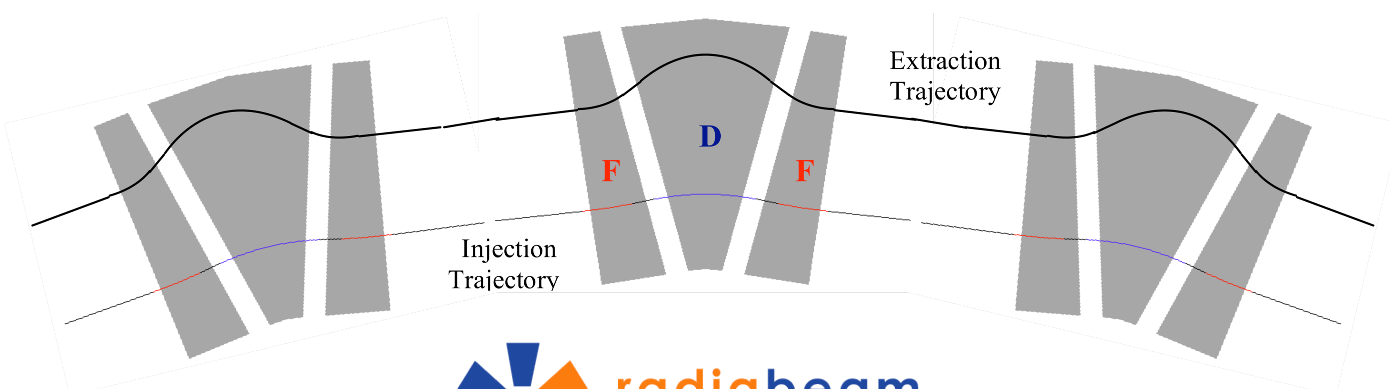
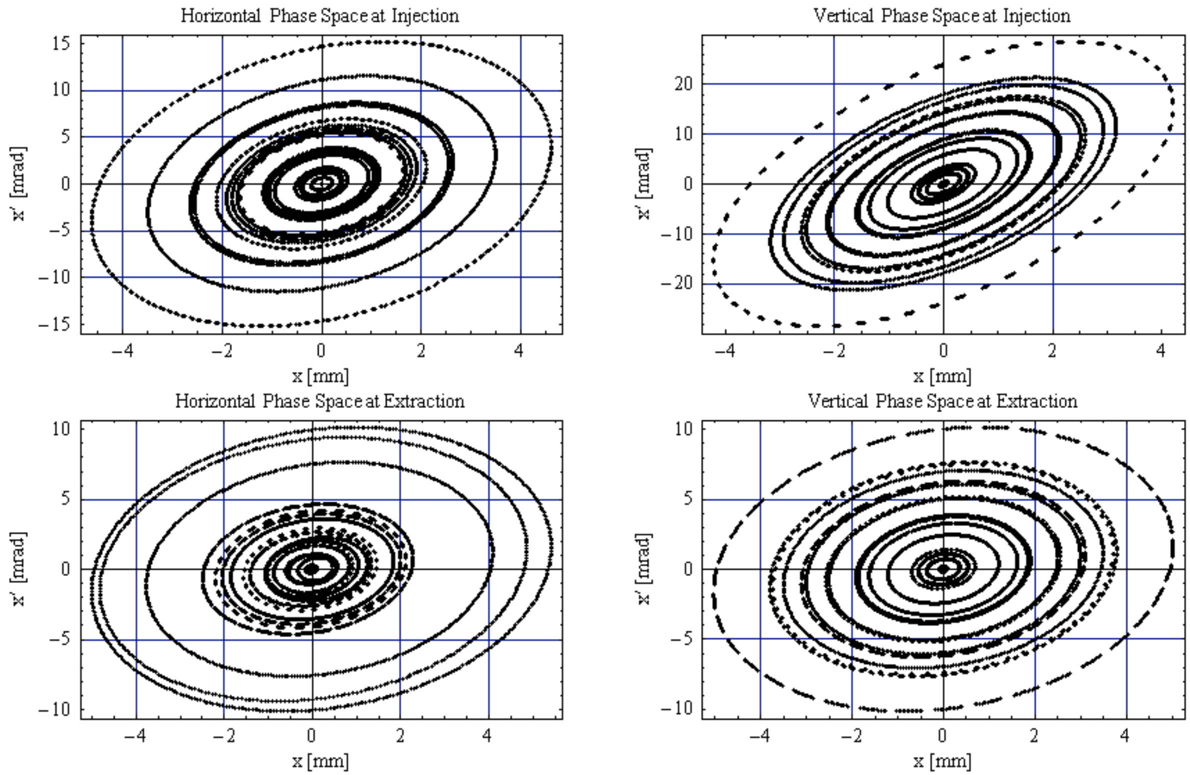
Electron Model Parameters

Energy at Injection/Extraction	400 / 1,500 MeV	218 / 817 keV
Circumference	807 m	18.0 m
Number of Periods	136	48
Lattice Type	FDF Triplet	FDF Triplet
Number of Particles/Pulse	$1.0 \cdot 10^{14}$	$5.5 \cdot 10^{10}$
Full (95%) Beam Emittance at Injection	100 π-mm-mrad	100 π-mm-mrad
Harmonic Number	24	4
RF Frequency at Injection/Extraction	6.357 / 8.228 MHz	47.7 / 63.5 MHz
RF Peak Voltage	0.8 MV	5.0 kV
Repetition Rate	2.5 Hz	2.5 – 5.0 Hz
Injection Period	1.0 ms	10 µs
Injected Current	1.4 mA	103 mA
Acceleration Period	7.0 ms	43 µs



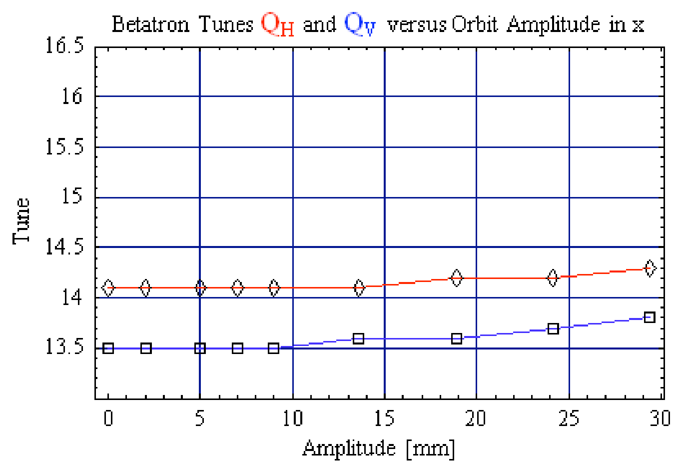
Tracking Simulations

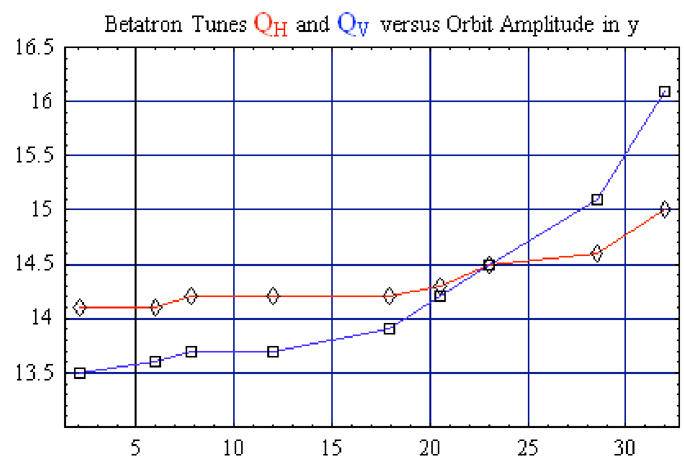
- 20 particles, 100 π mm-mrad (at injection)



Tracking Simulations

- Amplitude detuning





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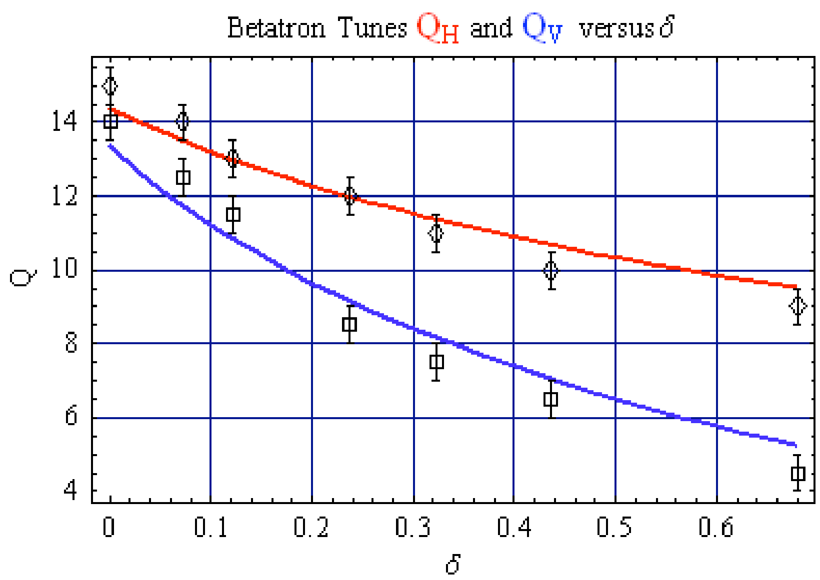
Tracking Simulations

- Comparison of tunes



Tracking Simulations

- May need to increase vertical focusing
- Need to use real magnet fields in simulation
- Perform error tolerance studies

Magnet Design

- Proton driver magnets not a problem
- e-model magnets more challenging
  - Very short, fringe fields must be controlled
- Two types of magnets, F and D, both with combined dipole and quadrupole fields

Magnet Type	Qty.	Clear aperture (mm)	Length (cm)	Gradient (kG/m)	Good field region (mm)
F-Sector Quadrupole	96	50 x 20	4.45	3.58	10
D-Sector Quadrupole	48	50 x 20	8.90	-3.14	10

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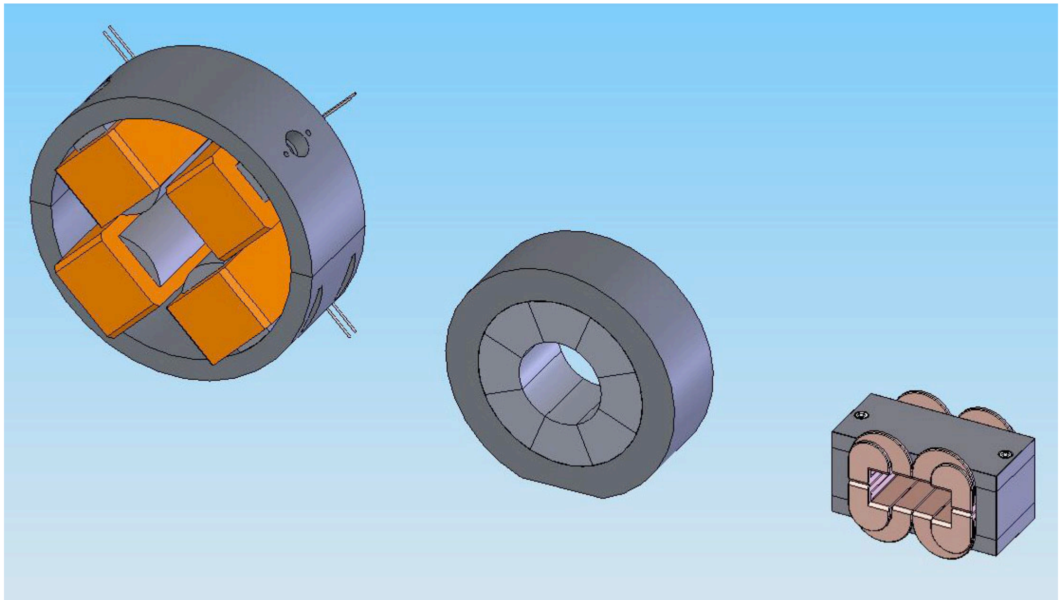
Magnet Design

- We considered three designs
- Panofsky is cheapest and best for fringe fields



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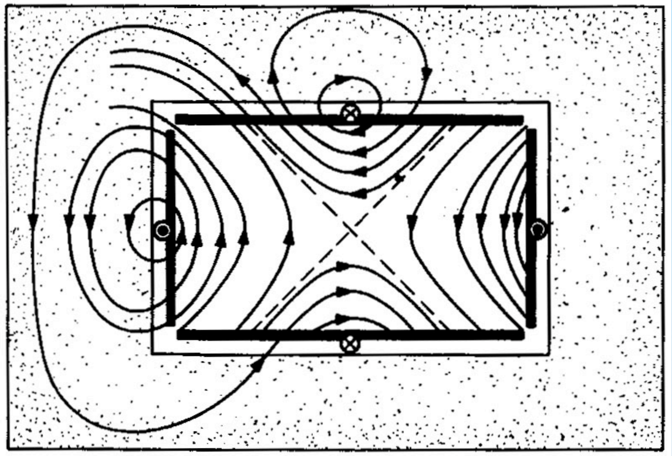
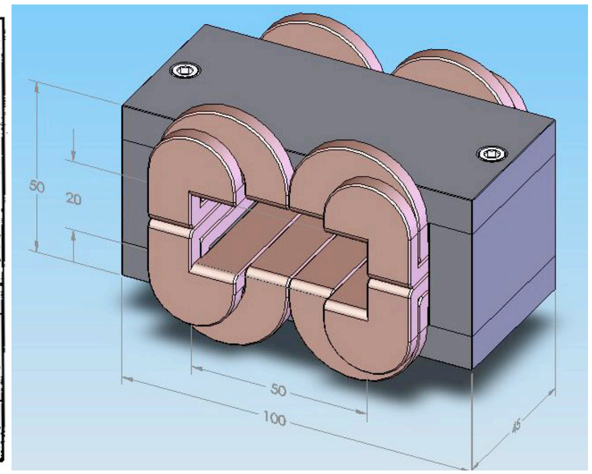
Panofsky Quad





Geometry type	Panofsky rectangular aperture quadrupole
Inner aperture	20 mm x 50 mm
Outer size	50 mm x 100 mm
Operating Gradient	3.58 kG/m
Excitation current (per coil)	54 Amp-turns
Cost per magnet	<$1000

Accelerating Cavity

- Ferrite tuned cavity
  - Robust and efficient, but larger and more complicated
  - Sweeping of large bias field in 43 μs is challenging
  - Magnetic field on axis
- MA (Finemet) broadband cavity
  - Simpler design, higher gradient, more compact
  - But less efficient (lower Q at high frequencies)

	AGS-FFAG	MINA
Number of cavities	20	2
Energy gain per cavity	25 KeV	500 eV
RF harmonic number	24	4
Revolution period	3.78 – 2.92 μs	85 – 66 ns
Frequency range	6.36 – 8.23 MHz	47.7 – 63.5 MHz
Total re-circulating current	4.24 – 5.49 A	103 – 134 mA
Sweeping time/Acceleration time	7.0 ms	43 μs

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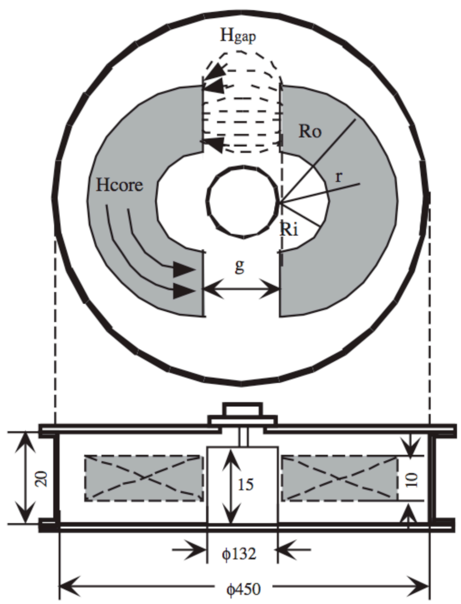
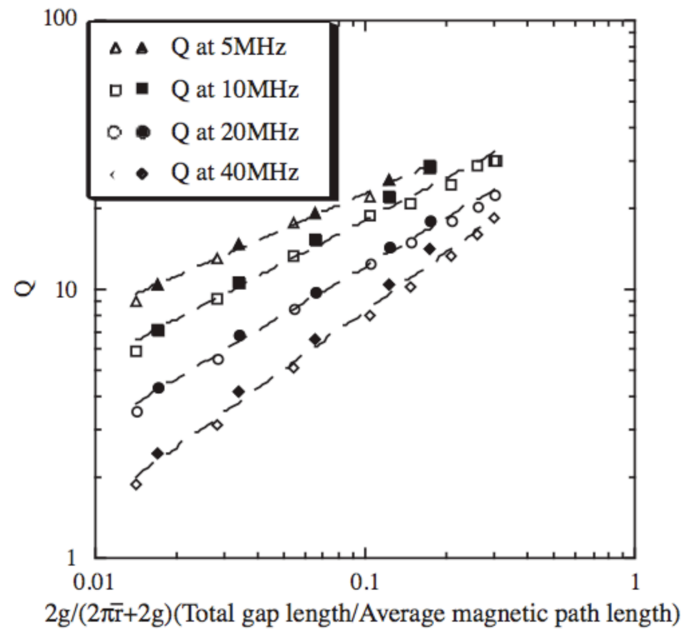
Accelerating Cavity

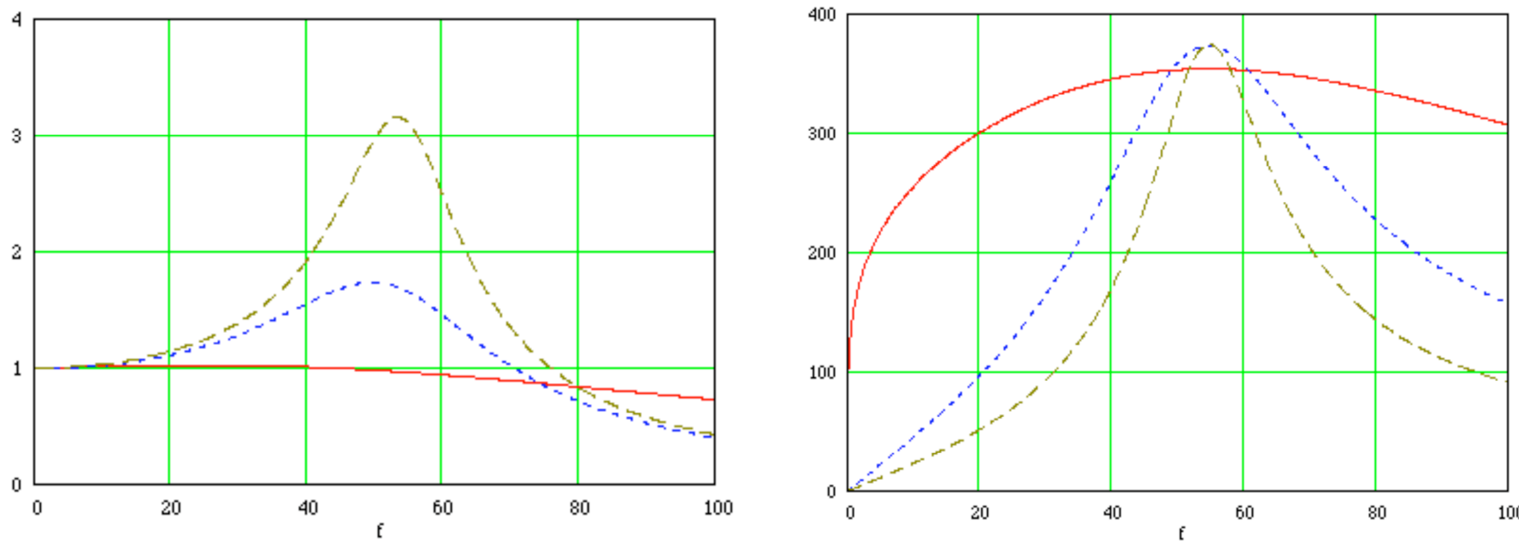
- Our approach: broadband cut-core
  - Smaller; active tuning not needed
  - For MINHA, no problem with thermal load





Accelerating Cavity

- Gap increases Q, but reduces bandwidth
  - Find optimal balance



Calculation of the cavity Q (left) and shunt impedance in Ohm (right) as a function of R F frequency in MHz for different gap (solid line - no gap, dotted line - 2 mm gap, and dashed line - 4 mm gap).

Accelerating Cavity

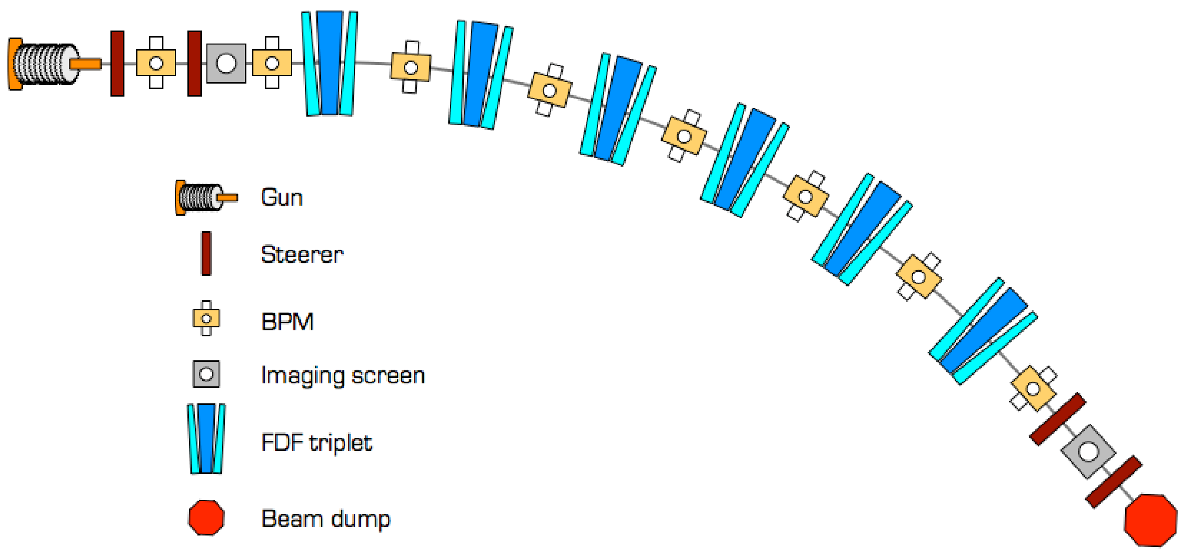
- In Phase II we will
  - Optimize degign
  - Build and characterize a cold-test cavity
  - Select RF power source

Injection

- 400 MeV, 10^{14} ppp, 0.5 tune depression
- Multiturn injection will be used on both proton machine and electron model
- For 100 turns, we need 1 mA gun, 218 keV
- Preliminary quote from BINP $100k
  – Triode gun emitting 30 kV + 80 cm electrostatic accelerator column

Octant Test

- Layout showing diagnostics



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Diagnostics

- RadiaBeam Diagnostics

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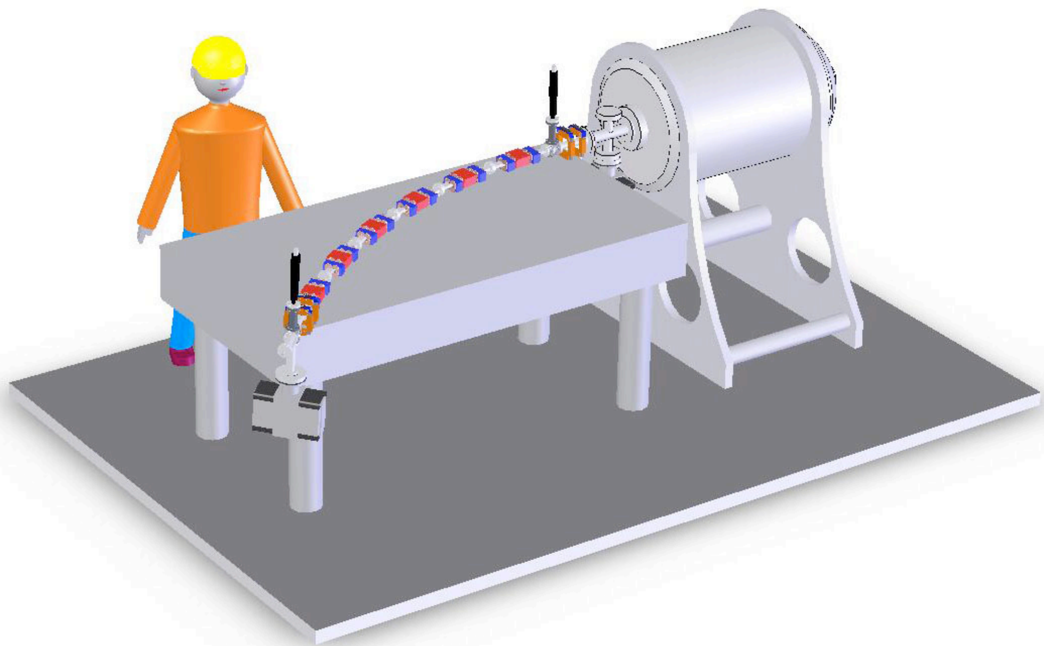
Octant Test

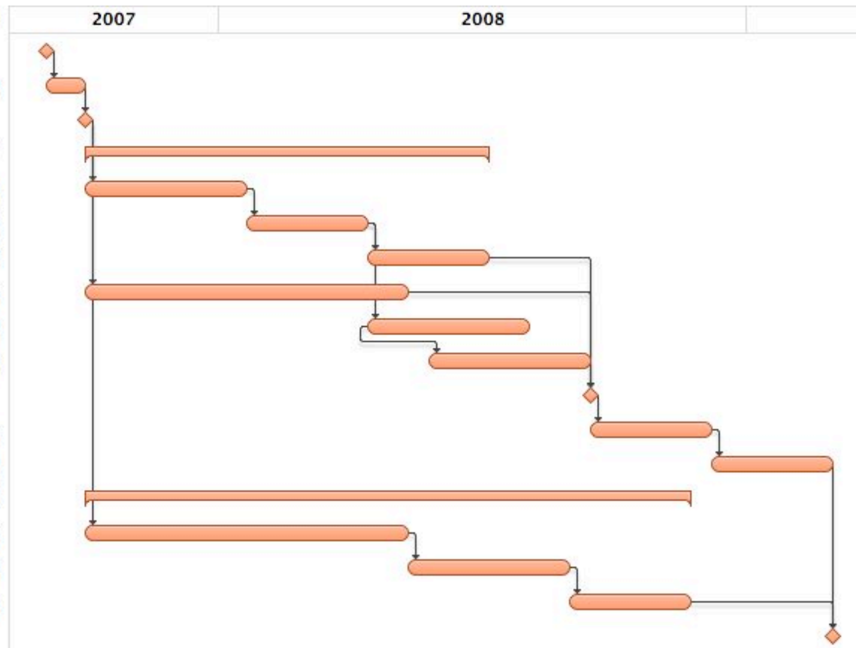
- Will be tested in PEGASUS lab at UCLA



Phase II Schedule

- Beginning 9/2007
- Fabrication finished late 2008

Task	Effort
1) Phase II Start	
2) Project Organization	4w
3) Design Review Meeting	
4) Magnets	40w
4.1) Field Map Simulation/Error Studies	16w
4.2) Engineering	12w
4.3) Fabrication	12w
5) Injector Design/Acquisition	32w
6) Diagnostics Design/Acquisition	16w
7) Control System Engineering	16w
8) Octant Fabrication Completed	
9) Assembly/Commisioning	12w
10) Experiment/Analysis	12w
11) Cavity	60w
11.1) Design/Simulations	32w
11.2) Fabrication	16w
11.3) Cold Test	12w
12) Phase II Completed	



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Beyond Phase II

- After Phase II, designs will be complete, and critical systems will have been tested.
- With additional funding, the collaboration can proceed to fabricate the full MINHA in 2009.
- **Experiment** can be performed on emittance growth due to systematic resonance crossings.

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